Camera Ab Initio: A workshop re-imagining the most familiar sensor

Meeting Scope and Objective

Emerging DoD and commercial scenarios envision large-scale deployment, coordination, and monitoring of ubiquitous imagers to keep an eye on complex environments. Stringent challenges in cost, platform constraints, and the effective exploitation of the resulting large volume of imagery motivate a principled re-examination of the structure, function, and roles of traditional visible and IR cameras.

Imaging has traditionally been defined as a process of measuring object attributes (potentially time varying) as a function of spatial coordinates. The most familiar form of an imaging sensor consists of a lens collecting light generated or reflected by objects and mapping it onto a light-sensitive medium (film or electronic sensors) such that the spatial relationship is preserved within the constraints of 3D to 2D mapping. In the past 50 years a number of novel imaging systems have been developed to work in different regions of the electromagnetic spectrum (from radio waves to X-rays) that depart radically from the visible imaging systems. These new imaging systems have been developed for applications ranging from astronomy, microscopy, medicine, and defense. Since the constraints and requirements for these systems are dramatically different, it follows that the design principles and structures of these systems also vary significantly.

Recent advancements in technologies for optical wavefront manipulation, optical detection, and digital post-processing have opened up new possibilities for imaging systems in the visible and IR regimes that differ dramatically in form fit and function from traditional cameras. Extensive cross fertilization of mathematical formulations and system architectures from different imaging modalities referred to earlier is expected to result in quantum leaps in the performance of more familiar imaging systems.

The main purpose of the workshop is to explore these new directions in imaging systems. In particular, the objective will be to explore the trade-off space between analog optical processing that is realized via pre-detection optics, on-chip processing within sensor arrays, and post-detection digital processing. The impact of these trades on systems-level performance is a particular concern. In particular, the output from imaging systems is often used in image exploitation such as target detection, identification, and tracking. Therefore another objective of the trade-off study will be the close incorporation of the image exploitation tasks within the image formation operation, possibly to the point of skipping image formation altogether.

This workshop will provide you with the proverbial "blank sheet of paper" for your explorations of new directions in sensor systems. We plan to begin the event by riling you up with a few thoughts presented by sensor system iconoclasts. We will next assemble you into vertically integrated virtual design teams and the creative work will begin. Your explorations in design space will be informed by recent advances in algorithms, materials, analog and digital devices, packaging, modeling, and optimization.

You will be concerned with optimizing traditional metrics like power, SNR, dynamic range, resolution, and cost. We would also like you to pay significant attention to systems-level metrics pertaining to the form, fit, and function of hypothetical deployed systems. This will involve considerations such as packaging, scalability, processing requirements and load balancing, communication and cooperation, flexibility in multiple functions, and control of adaptive feature sensing for enhanced exploitation. We will also be concerned with the impact of new architectures on platforms and deployment.

In these studies, we will be especially concerned with possibilities for co-design and joint optimization of traditionally independent subsystems. In effect we are looking for opportunities to perform a load balancing among the optical, digital, and computational processing components of our systems. We anticipate widely varying definitions of the concepts of “image” and of “camera.” We hope to end up with evidence of new methodologies for creating and prototyping revolutionary approaches to the imaging requirements of the DoD.

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Meeting Agenda

Monday, April 28, 2003

7:30 - 8:30 a.m. ***Registration and Continental Breakfast***
8:30 - 8:45 am *Dennis Healy and Ravi Athale, DARPA/MTO*
8:45 - 9:05 am *Ed Watson, AFRL*
9:05 - 9:15 am *Joe Mait, ARL*
9:15 - 9:35 am *Dean Scribner, NRL*
9:35 - 9:55 am *Alan Van Nevel / Gary Hewer, NAVAIR, China Lake*
9:55 - 10:15 am *Jim Brase / Eddy Stappaerts, Lawrence Livermore National Labs*

10:15 - 10:45 *Break*
10:45 - 11:15 am *Dave Brady, Duke University*
11:15 - 11:45 am *Vladimir Brajovic, CMU,*
11:45 - 12:15 pm *Steve Zucker, Yale University*

12:15 - 1:15 *Lunch*
1:15 - 1:45 pm *Nicholas George, University of Rochester*
1:45 - 2:15 pm *Len Buckley, DASRPA/DSO*
2:15 - 2:45 pm *Dennis Braunreiter, Raytheon*

2:45 - 3:15 *Break*
3:15 - 5:30 pm *Breakout Group Discussions*

Tuesday, April 29, 2003

7:30 - 8:30 am ***Registration and Continental Breakfast***

8:30 - 10:00 am *Breakout Group Discussions (cont.)*

10:00 - 10:30 *Break*

10:30 - 12:30 pm *Breakout Group Presentations, Discussion, Wrap-up*

<u>TOPICS FOR WORKING GROUP DISCUSSIONS</u>

GROUP I:
Discussion Leader: Dave Brady, Duke University
Group Members: Jim Brasse, Lawrence Livermore Labs; Rick Morrison, Distant Focus; Bob Pless, Washington University; Dinesh Rajan, SMU; Clay Stanek, ANZUS Corp; Ed Watson, AFRL; Wayne Wolf, Princeton U.

Your objective is to design a visible/thermal imager that will wrap around a soldier's helmet to provide 360 degree awareness. As such, the camera design must be thin and conformal. We require the system to perform pre-attentive fusion between visible and thermal modality, multiple and adaptive foveation and cueing. The system should be capable of video rate operation. Particular emphasis should be placed on low power consumption to extend battery life. While we do not give any specific spatial resolution or dynamic range goal, the system design should provide a parametric dependence between required hardware technology and the resultant system performance. It is not necessary to consider characteristics of the display device.

GROUP II:
Discussion Leader: Dean Scribner, NRL
Group Members: George Barbasthathis, MIT; Ron Coifman, Yale; Ed Dowski, CDM Optics; Jim Fienup, U of Rochester; Jody O'Sullivan, Washington U; Robin Dawson, Sarnoff Corp; Nicholas George, U of Rochester.

The suggested theme for your group will be imaging systems which exploit phase information in interesting and innovative ways. This could include the use of phase diversity in atmospheric correction, coherence imagers, interferometric imagers, aperture synthesis and the like. What is new or possible here for imagers looking at the earth from orbit, for looking up from the earth to high altitudes, and especially for horizontal path imagers? Can these work on DoD mobile platforms? Can we quantify the useful information provided by such imagers as compared with standard intensity-only imaging? You should also consider the form and fit of such a sensor (in addition to the described function) and have maximum flexibility that will allow the sensor system to be efficiently deployed on a variety of platforms.

GROUP III:
Discussion Leader: Joe vander Gracht, HoloSpex, Inc.
Group Members: Shaya Fainman, UCSD; Gary Hewer, LLNL; Mike Haney, U Delaware; Ron Stack, Distant Focus; Steve Zucker, Yale U; Peter Catrysse, Stanford.

The suggested theme for your group will be imaging systems which provide and exploit higher dimensional information than that provided by customary 2-d imagers. Relevant dimensions to consider would include 3-d spatial information, spectral information, and temporal information. Feel free to consider other dimensions such as polarization if you think it productive. Specific approaches for such systems might include sensors which detect and utilize geometric features such as projections, line integrals, and slice integrals. Other geometric representations such as level-sets may also be of interest. The specific utility of exploiting higher dimensional information should be articulated in the context of notional applications. You should also consider the form and fit of such a sensor (in addition to the described function) and have maximum flexibility that will allow the sensor system to be efficiently deployed on a variety of platforms.

GROUP IV:
Discussion Leader: Eddy Staepert, Lawrence Livermore Labs
Group Members: Vladimir Brajovic, CMU; Dennis Braunreiter, Raytheon; Marc Christiensen, SMU; Kenny Kubala, CDM Optics; Demetri Psaltis, CalTech; Mark Neifeld, U Arizona; Rob Nowak, Rice U.

Your group has the charter of abandoning the view of imaging as spatial maps of scene irradiance resulting in a pixel representation. The ultimate objective of an imaging sensor is to detect interesting objects in a scene, recognize and classify them and track them. For these operations it may not be necessary to produce pixel maps with ever increasing resolution. Your group should consider alternate representations of the scene/object that are produced directly from the sensor. However, we do want you to consider the potential gain that can be obtained by a joint design of the optics, detector arrays (including possible on-chip processing) and post detection processing algorithms and hardware. In other words, how can we extract maximum information from the photons that are available from the scene? You should also consider the form and fit of such a sensor (in addition to the described function) and have maximum flexibility that will allow the sensor system to be efficiently deployed on a variety of platforms.